CHAPTER 3

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN NITRATE CONTAMINANT REMOVAL BY ION EXCHANGE

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1.0 INTRODUCTION

1.1 Need For This Verification Testing Plan

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing the ion exchange process for nitrate removal. The Safe Drinking Water Act and its state counterparts set standards for water quality regarding certain contaminants, which are known to occur in public water supplies. The frequency of testing for these contaminants is also specified. However, the Act does not set standards for the design, performance, testing or operation of treatment facilities for the regulated contaminants. To a certain extent, individual States place requirements on some of these areas not covered by the Act. For example, there are training and certification programs for operators of treatment plants and design reviews given to proposed treatment facilities followed by a plant operating permit procedure. However, in most cases, operator training and design reviews are not familiar with the variety of designs, which use the specialized ion exchange technologies. This ETV Testing Plan provides background information and testing procedures, which will be of service to owners, operators, state regulators and manufacturers who must deal with these unfamiliar technical subjects. The responsibility to make effective treatment rests with the States and the professional disciplines and organizations involved in the effort and in particular on the equipment designer and supplier or manufacturer of the treatment system.

Under the ETV testing program, it is the manufacturers responsibility to retain a qualified Field Testing Organization to conduct tests on the plant by following an NSF approved preset testing plan contained in the Product-Specific Test Plan (PSTP). Other subjects treated in the PSTP are set forth in the ETV Protocol Document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies." This Equipment Verification Testing Plan is applicable only to processes using ion exchange materials as the media in the nitrate removal processes.

1.2 Manufacturer’s Responsibility

In order to participate in the equipment verification process for nitrate removal, the equipment Manufacturer shall retain a qualified Field Testing Organization to employ the terminology, procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of PSTP. The testing procedures shall generally follow the tasks that are outlined and described in this document. An attempt has been made to provide test descriptions to be appropriate to all processes using ion exchange rather than to a specific design of a process. However, variations in these tasks may be required to modify or adapt to specific process designs or plant situations. A suggested outline and format of the procedures written by the Field Testing Organization for each task is given. The outline for each task will usually contain the following sections:

- Introduction
- Objectives
- Work Plan
- Schedule

An overview of the Tasks is given in Section 4. A list of definitions and terms, which are peculiar particular to nitrate ion exchange, is given in Section 6. The specific Tasks to be included in each PSTP are described in Sections 7 through 13.

2.0 GENERAL BACKGROUND ON ION EXCHANGE PROCESSES

2.1 Description of Processes

This verification testing plan applies to a wide scope of equipment types which use ion exchange processes. There is no lack of creativity among ion exchange process designers who have had over fifty years since the availability of synthetic ion exchange materials to exercise their ingenuity. It is not the intention of a specifically defined test plan to limit this scope nor to discourage innovation. On the other hand, regardless of novelty, all ion exchange processes are governed by the same basic ion exchange reactions which constitute the various processes.

Among various ion exchange materials available for nitrate exchange, synthetic polymeric resins that carry exchangeable anions are most widely used. Regardless of exchange materials, the nitrate exchange process can be expressed in two steps, adsorption and regeneration as shown below:

$$(\text{Ion Exchanger})\text{Cl}^- + \text{NO}^-_{3\,(\text{aq})} \rightarrow (\text{Ion Exchanger})\text{NO}^-_3 + \text{Cl}_{(\text{aq})} \qquad \text{Adsorption Step}$$

$$(\text{Ion Exchanger})\text{NO}^-_3 + \text{Cl}^-_{(\text{brine})} \rightarrow (\text{Ion Exchanger})\text{Cl}^- + \text{NO}^-_{3\,(\text{brine})} \qquad \text{Regeneration Step}$$

The Adsorption Step consists of contacting the nitrate-laden water supply with a bed of Ion Exchanger in the chloride form. The nitrate ion is removed from the water and, in exchange, the chloride ion is added to the water. The opposite exchange occurs in the Regeneration Step where the Ion Exchanger is restored to its initial chloride condition where, after rinsing, it can be reused.

If the process were 100 percent efficient, only one chloride ion would be required to remove one nitrate ion from the water supply. In terms of energy demands, the Adsorption Step occurs with the equilibrium favoring the product side of the reaction, nitrate ion is much preferred by resins in preference to chloride. All resins are selective for nitrate over chloride. Therefore, for the Regeneration Step, an energy price must be paid by using an excess of chloride to drive the reaction to the right.

The nitrate exchange process can be represented by a single overall metathesis or exchange reaction, which is the sum of two reactions (adsorption and regeneration steps) with a resin giving a net result:

$$\text{NO}^-_{3\,(\text{aq})} + \text{Cl}^-_{(\text{brine})} \rightarrow \text{NO}^-_{3\,(\text{brine})} + \text{Cl}^-_{(\text{aq})} \qquad \text{Basic Nitrate Ion Exchange}$$

Wherein a chloride ion from a concentrated brine replaces a nitrate ion in the untreated water. The net result is removal of nitrate from the water supply and production of waste nitrate brine. The water softening process can be represented by a similar net exchange reaction:

$$Ca^{2+}_{(aq)} + 2Na^{+}_{(brine)} \rightarrow Ca^{2+}_{(brine)} + 2Na^{+}_{(aq)} \qquad \text{Ion Exchange Softening}$$

Superficially, the processes appear similar; but they are quite different because of the different stoicheometries which drastically influence process efficiency. In the nitrate/chloride exchange, the number of nitrate ions transferred to the brine is directly proportional to $Cl^{-}_{(brine)}$ according to the law of mass action. To drive the nitrate reaction to the right, an excess of chloride brine ions is required. However, in the softening case, the amount of waste calcium ions transferred to the brine is proportional to $(Na^{+}_{(brine)})^2$ according to the mass action law. In the case of waters of normal hardness, and the usual brine concentrations, the efficiency is nearly 100 percent, requiring relatively little excess brine. Process designs for efficient water softening, therefore, are not directly applicable to nitrate removal.

Because the basic process is carried out indirectly through a sequence of steps, efficiency is greatly dependent on the nature of the ion exchanger and the physical methods used to bring the water supply into contact with the Ion Exchange medium and then to carry out the regeneration. This situation invites a variety of process designs each employing specific chemical, hydraulic, and mechanical methods. In the softening case, both the adsorption and the regeneration reactions favor the right hand side of the two equations because of the divalent nature of the calcium ion. (This is probably the least understood aspect of comparisons between nitrate ion exchange and softening). The practical result is that near stoichiometric quantities of salt regenerant are required in softening, whereas in the nitrate case ten (or higher) to one are required for a complete regeneration.

The design must bring the water supply into close contact with the Ion Exchanger over a specific time period and in a three-dimensional uniform flow. Engineers have devised several ways to do this but it is usually done by placing the Ion Exchanger in a filter bed or columnar arrangement, distributing the untreated water over the bed and allowing water to flow through at uniform rates; then uniformly collecting the treated water near the exit of the bed. The same type arrangement is used for the Regeneration Step.

The competition between the major ions present in a water supply for taking over an ion exchange site is also great enough to be of concern in the design of the equipment and the process. After the Ion Exchanger is exhausted, the different ions will be concentrated in the resin bed according to the chemical equilibrium laws of chromatographic distribution. Consequently, the use of different ion exchange resins and different methods of adsorption and regeneration are employed to overcome any difficulties, which this may cause. For example, the regenerations will be conducted by flowing the regenerant through the bed in the same or opposite direction that the water flows in the adsorption step.

Rinsing and wasting the brine from the bed is also performed in different ways and gives rise to different rinsing efficiencies. In some cases sophisticated designs will reuse at least some of the rinse water, waste brine, or backwash water. Further variations in process designs are made to ensure that the resin bed is always in a uniformly packed condition to prevent channeling of fluid through the bed and reducing the physical contact time between the resin and the fluid.

In essence, each manufacturer has a large number of variables to deal with in how to accomplish the simple Basic Ion Exchange process with the particular design and operation of plant equipment. Each may claim some aspect of the design, which makes it superior to another, or make some claim regarding proprietary or breakthrough designs.

2.2 Classification of Nitrate Ion Exchange Processes

For the purpose of this verification testing plan the different process designs will be classified according to common characteristics and expected performance levels. For example, design Class 1 will usually be used for small units where process efficiency and waste production are of little concern, but high reliability, ease of operation and water quality objectives are important. In contrast, other design classes may be used where there is concern about waste disposal and may require more sophisticated regeneration procedures, adding to the complexity of operation. One cannot, therefore, state that one design is superior to the other, but only to the extent that the treatment and other related objectives are similar.

The verification testing program will verify manufacturer's objectives regarding the performance of the equipment. The manufacturer will classify the design according to the following design classifications, provide flow diagrams of the design and provide projected performance characteristics of the plant.

2.2.1 Fixed Bed Designs

Fixed bed designs employ the ion exchange resin placed in a vessel that is stationary and within which both the adsorption and regeneration steps are conducted. The contact between resin and the water (or regenerant) is accomplished by flowing the water (or regenerant) through the stationary vessel. This is the most common type design. (Some movement of the resin occurs within the vessel during the backwash, declassification, and rinsing procedures.) The placement and operation of a number of valves accomplishes the changes in the flow of fluids through the bed in a fixed bed design.

2.2.1.1 Class 1. Conventional Fixed Bed. This is the simplest type of design and uses the same equipment and regeneration method that is manufactured for water softener use. Instead of using a resin for softening water (cation exchange resin) this resin is replaced with an anion exchange resin. The specific gravity of anion exchange resins is much lower than cation resins. Therefore, the backwash step and the ion exchange vessel internal components may need to be modified for anion exchange processes. The bed is run to near exhaustion, then regenerated with excess salt to ensure regeneration in a down flow direction then rinsed. It is commonly thought, although erroneously, that nitrate ion exchange differs only from water softening in the kind of resin that is used and the chemical, physical, hydraulic, and regeneration processes are identical (see above). Although such designs may remove nitrate and operate reliably, they will also use excessive salt regenerant and may also produce excessive wastewater. A Class 1 design is likely to be low in capital cost because no special design considerations for nitrate removal chemistry are included and designs are made for the softening mass market. Normally, the sequence of steps for one cycle in a Class 1 design is adsorption, back wash, regeneration and finally, rinse.

2.2.1.2 Class 2. Up Flow Regeneration Fixed Bed. This fixed bed design employs regeneration in an up flow regeneration mode. Distributors within the vessel and valving are designed to accommodate this design feature. Again, this type of design is primarily used in softening where very low levels of contaminant ion are required to meet water quality objectives. Problems encountered are that when brine flows upward through the resin, the distance between resin particles tends to increase, as the bed tends to expand upward. The result is the regenerant will channel through the bed with reduced contact with the resin. Designers must somehow compensate for this problem, e.g., by employing a blocking flow.

The advantage of this design is that the resin at the bottom of the bed has virtually all nitrate removed so when the bed is placed in service, no nitrate appears in the initial portion of product water. However, continued production causes nitrate to gradually rise, with a rate dependent on amount of regenerant used. A second advantage of this design can be realized if the nitrate on the resin is concentrated at the top of the bed when regeneration starts. Large amounts of nitrate can be removed from the top of the bed by the regenerant and give good regeneration efficiency. The amount of nitrate at the top of the unregenerated bed varies with water composition. If sulfate is present, sulfate concentrates at the top of the bed and this advantage is diminished or can become a disadvantage. In the latter case, declassification of the resin before regeneration can move some nitrate to the top of the bed.

In general, a Class 2 design can give a product water very low in nitrate initially. The more nitrate removed from the treated supply, the more untreated water can be blended in to give an acceptable nitrate level. This in turn is translated into use of smaller sized vessels and amounts of medium (lower capital cost). However, greater salt demands are the trade off.

2.2.1.3 Class 3. Fixed Bed With Partial Regeneration And Declassification. This method was developed by the USEPA for demonstration in McFarland, California, and is employed in several locations in the U.S. where sulfate is present in the feed water. This design is more complex than the above systems to minimize the amount of brine and wastewater. The process uses modified vessel designs with efficient flow distributors and bifurcated collectors. Down flow adsorption is directly followed with down flow regeneration. This takes advantage of the concentrated nitrate at the bottom of the bed at the end of the adsorption cycle to give high nitrate removal efficiency. The bed is only partially regenerated, i.e. large amounts of brine are not used to remove all nitrate from the bed, only sufficient nitrate is removed to meet water quality objectives. The next step is to declassify the bed, (accomplished by a series of five uneven back washes via the bifurcated collector design, to mix the bed) and distribute the nitrate remaining on the bed uniformly throughout the bed. This is necessary to give a constant level of nitrate in the product water as the bed is exhausted.

The advantages of this design are more efficient use of brine and less wastewater production than the above designs especially if sulfate is present.

2.2.2 Moving Bed Designs

Moving bed designs require that the resin bed (or part of the bed) move from place to place at some part of the process cycle. An example is to use one vessel to perform the Adsorption Step, then remove resin and place it in a second vessel where the Regeneration Step is performed. Then move the regenerated resin back into the first vessel. One of the advantages of this type design is that less resin inventory is required.

2.2.2.1 Class 4. Loop Designs. These designs are also referred to as moving packed beds or by different names such as Higgins or Asahi and their variations and have a place in the history of nitrate treatment, being the first large-scale plant design used in the U.S. at Garden City Park, N.Y. Their common feature is the movement of resin from one vessel to another for different parts of the cycle.

In the Higgins Loop reactor, the adsorption occurs in a down flow mode through a first vessel. Then, the top portion of the bed is moved (pulsed) to a regeneration vessel and regenerated resin is pulsed back to the bottom of the first vessel. The adsorption and regeneration steps can be conducted simultaneously but in different vessels. Advantages depend on water quality. On Long Island, low sulfate water concentrated nitrate at the top of the bed, which is efficiently regenerated and the down flow mode in a separate vessel avoids the channeling problems encountered in the fixed bed Class 2 design. Further advantages claimed are that lower resin inventories are required making capital costs lower. Critics claim low resin life, because of resin attrition caused by pumping resin slurries from one vessel to another.

The Asahi design is quite complex. Some features are:

1) up flow adsorption and high flow rates, which pin the bed to the top portion of the adsorption vessel, while the lower portion of the bed is moved by fluidization to a regeneration vessel;
2) after exhaustion the flow stops, the bed falls and draws in regenerated, rinsed resin; and
3) absorption flow is started again, pinning the fresh resin against the top of the vessel and moving the spent lower portion to regeneration.

The advantages appear to be the same as the Higgins reactor except resin is moved by fluidization rather than mechanical pumping.

2.2.2.2 Class 5. Carousel Designs. In this design, the resin bed moves within several vessels within which resin is contained. The vessels are mounted in "merry-go-round" configuration and gradually step from position to position by rotation of the entire mechanism. The circular platform structure contains orifices through which the fluids enter and exit the individual vessels. When the vessels are in positions e.g. 1 through 10, they are in the adsorption section of the carousel. When they are in positions e.g. 11 through 15, they are in the regeneration section, and finally when they are in the last section, the vessels are rinsed. This design has potential to have the highest regeneration efficiency and lowest wastewater production because various piping arrangements can easily recycle brine and rinse water.

3.0 NSF QUALIFIED TESTING ORGANIZATIONS

Testing and evaluation of equipment covered by this Verification Testing Plan will be conducted by a Field Testing Organization that is qualified by the NSF and selected by the Manufacturer. The water quality analytical work to be carried out as a part of the Verification Testing Plan will also be contracted by the manufacturer with a state-certified, third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF PHASES AND TASKS

The PSTP will include a Testing Plan with detailed tasks described and scheduled that will be followed by the NSF qualified field testing organization. The PSTP plan will be formulated by the Field Testing Organization to be effective for the particular plant design, operation and field situation. Wide variability in PSTP plans is anticipated because of these factors. The tasks listed below and detailed throughout this document are formulated to represent the content, vocabulary, organization and quality of testing and evaluation procedures anticipated by NSF to be included in any PSTP. The Field Testing Organization may add other tasks. If the tasks listed below are eliminated or substantially modified, a reason for doing so should be given.

Three phases of testing are to be included in the Verification and Testing Plan.

- The **first phase** consists of preparation and plant start up. The scope of this phase will depend on whether or not the equipment has already been installed at a treatment plant site and is already treating water or if the plant will be delivered to the site and will require set up and start up procedures.

  A meeting of testing personnel with the plant manufacturer will be held to review the material contained in the PSTP presented by the Field Testing Organization. Much material regarding the plant and its operation were provided in the PSTP as set forth in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies." This material will include, design classification, drawings and diagrams of the plant design, the start up and operating procedures. This meeting will allow any questions concerning the plant and the testing program to be addressed. The manufacturer will confirm the items which will be tested for during the program and present the objectives concerning operation, make projections of the plant performance characteristics, and review any critical or key measurements to be made.

  The meeting or a part of the meeting should take place at the treatment plant site where various features and components can be directly pointed out and demonstrated. If the plant is not yet started, the start up could take place at this time.

- The **second phase** is the field testing phase, which will evaluate performance of the equipment over a 60-day period.

- The **third phase** will be conducted throughout the testing period to ensure that the data are collected in a reliable and retrievable manner, properly and completely reported on a timely basis. A Data Manager will be responsible for these tasks.

The three phase Testing Plan outlined below is comprised of 8 separate tasks, which are outlined in the following sections.

4.1 Phase 1. Preparation

4.1.1 Task 1. Preparation, Coordination, Start Up

An orientation meeting will be held in preparation for the testing program. The manufacturer will meet with the field testing organization personnel to review the plant and process design and clarify the testing program and schedule. It is recommended that a field visit to the plant be made to acquaint the testing personnel with details of the plant site. Discussion of the program, its objectives, and responsibilities of each participant will be clarified. If the plant is not already operating, the plant will be started approximately 15 days before field tests begin.

4.2 Phase 2. Field Testing

4.2.1 Task 2. Initial Plant Characteristics

Initial tests will be conducted to measure the plant's basic capabilities and characteristics. These tests will be conducted to produce base line information, which can be used to evaluate changes, which occur as the plant ages. If the plant does not meet water quality objectives, the Field Testing Organization will be notified and adjustments made.

4.2.2 Task 3. Daily Testing and Data Collection

Routine measurements and data recording will be conducted on a daily basis for at minimum a 60-day test period.

4.2.3 Task 4. Cross-Connection And Mechanical Inspection

Two certified or registered professionals will perform inspections of plant equipment and operation:

1) a cross-connection specialist will inspect and test all cross-connection control and back flow prevention devices, and

2) a mechanical engineer will inspect all electrical and mechanical equipment for proper placement and operation.

4.2.4 Task 5. Evaluation of Secondary Data

Data obtained by the owner/operator the 60-day period during regular plant operation will be reviewed to evaluate the data collection, management and reporting system of the plant. The accuracy of the data and information as well as its adequacy will be evaluated. Data found to be accurate can be used to supplement the evaluation and testing program.

4.2.5 Task 6. Continuous Nitrate Analysis and Monitoring

In order to evaluate the reliability and stability of the plant operation. Frequent sampling and analysis of the three different streams (feed, treated and blended) for nitrate levels should be performed. High frequency sampling (at approximately six-minute intervals) is best done with modern nitrate measuring instruments. Because of recent improvements and the popular use of automatic nitrate monitoring instruments at several nitrate plant locations, it is highly feasible to do close monitoring of nitrate levels in multiple process streams. It is highly desirable that one nitrate monitor be used to monitor three different process streams over a period of 60 days. If an automatic monitor is not used, manual samples should be taken from the three different streams as frequently as feasible for analysis.

4.2.6 Task 7. Quality Assurance and Quality Control

A Quality Assurance and Quality Control (QA/QC) program will be followed to ensure adequate quality of the data collected.

4.3 Phase 3. Reporting

4.3.1 Task 8. Data Collection Methods, Management and Reports

Data collection, management and reporting will be tasks, which are closely integrated. The contents of the draft and final report will include specific summaries and items to complete the evaluation of the plant performance.

5.0 TESTING SCHEDULE

The PSTP will contain a Schedule of Tasks.

Task 1, Preparation, Coordination and Start Up, shall be performed before the plant testing program begins. The plant shall be operated for at least ten cycles before tests can begin.

Task 2, Initial and Final Plant Characterization, shall be performed at the beginning and end of the 60-day test program.

Task 3, Daily Testing and Data Collection, typical water quality and operational monitoring shall be performed at least three times per day and additional data collection shall be performed every two weeks.

Tasks 4, Cross Connection and Electromechanical Inspection, and 5, Operation Evaluation and Examination of Records, will be done near the end of the 60-day test period.

Task 6, Continuous Nitrate Analysis and Monitoring, shall be at least three times per day over the 60-day test period

Tasks 7, QA/QC, and 8, Data Collection Methods, Management, Reporting, will be conducted throughout the test program.

6.0 TERMINOLOGY FOR VERIFICATION TESTING AND EVALUATION

6.1 Perspective on Terminology

A uniform and consistent terminology shall be used for the evaluation, testing, and reporting of nitrate systems. This will allow potential users to make direct comparisons between different systems and be able to choose the most suitable system for their needs. Unfortunately, ion exchange technology is not consistent and varies with the application of interest. A set of terms will be used that are derived from the Safe Drinking Water Act (SDWA) itself, from standard chemical terminology, and which are specifically related to nitrate ion exchange. It is necessary to make distinct and precise definitions because the ion exchange process, as used for nitrate removal from municipal water, is a relatively new and highly specialized water treatment method. Ion exchange for nitrate removal is considerably different from older and widely used technologies of ion exchange for softening or ion exchange for demineralization. Because of these differences, a different terminology is used to be compatible with the SDWA and to represent the technological differences between nitrate removal and other applications such as softening. Although this discussion will appear superfluous to those skilled in ion exchange technology, it is believed to be useful to those who are not.

For example, the Safe Drinking Water Act specifies Maximum Contaminants Level (MCL) values in chemical concentration terms of **milligrams per liter** (mg/L) of the contaminant. Older technology conventions express concentrations in terms of mg/L of calcium carbonate equivalents or equivalent grains of calcium carbonate or electrical conductivity. This may be suitable terminology to describe hardness removal or demineralization, however, for nitrate or any other contaminant, it makes little sense to refer to nitrate as calcium carbonate or grains of calcium carbonate or conductance equivalents, especially when the SDWA avoids these terms.

Furthermore, the major differences between ion exchange for nitrate removal and ion exchange for softening relate to the basic chemistry differences between the two processes. It is appropriate to use a different terminology. The major differences are:

A. Inefficiencies Due to Presence of Other Ions

Sulfate ion interferes heavily in nitrate removal. Chloride and bicarbonate also interfere. Removal of calcium ion by softening resins is not as sensitive to these or other cations. Feed water composition of all major anions is important in nitrate treatment.

B. Process Efficiency

The nitrate removal process is less efficient than softening. (For example, at typical regeneration doses of 5 - 10 lbs/cubic foot of resin, the hardness leakage will be close to zero, whereas the nitrate leakage will be 10 to 20 mg/L depending on water quality.) Designing and operating a plant for minimum regenerant usage in nitrate removal is critical and process designs different from designs for softening are required. Use of salt in the softening process is of less concern because of the greater efficiency of regeneration. Use of salt in the nitrate removal process is a serious concern because of the relatively greater quantities of salt required and the cost of disposal.

C. Product Water Quality

In treatment for nitrate removal, processes can be designed to allow some nitrate to pass through the bed. In softening, only very small amounts of hardness ions are allowed to pass through. To hold nitrate removal to the same standards of removal as hardness ions can be counter-productive by increased complexity, lower efficiency and higher cost of the process.

The PSTP will use the following terminology when describing the plant equipment, its operation and the testing and evaluation procedures. The reports prepared in Task 8 will use also use the following terminology in describing the evaluation of the plant. This test plan also uses the terminology presented here.

6.2 Terms Defined

Adsorption - (Same as Ion Exchange Adsorption). The step in the ion exchange process which removes nitrate from water by chemical or physical attraction to a medium such as an ion exchange resin. It is also referred to as the SERVICE step or the EXHAUSTION step.

Adsorption Isotherm - A graph showing the amount of material adsorbed as a function of the equilibrium concentration at a fixed temperature per unit weight of ion exchange material.

Anion - A negatively charged ion. The major anions of concern are nitrate, sulfate, chloride and bicarbonate.

Anion Exchange Resin - A polymeric material in the form of granular particles or spheres within which positively charged ionic sites are chemically bound and which can adsorb anions from an aqueous solution by the ion exchange reaction.

Attrition - Breakage and wear of ion exchange resins.

Back Washing - The upward flow of water through an ion exchange bed to clean it of foreign material and reduce the compaction of the resin bed. Usually the bed is fluidized by the upward flow of water.

Batch Contact - A method of using ion exchange materials in which the resin and liquid to be treated are mixed in a vessel and the liquid is decanted off after equilibrium is attained.

Bead Count - The evaluation of an ion exchange material's physical quality by microscopic evaluation and determination of percent whole, cracked, and broken beads in a wet sample.

Bed - The ion exchange material contained in a column or vessel of an operating unit.

Bed Depth - The height of the resin material in the column after the exchanger has settled into a packed bed condition.

Bed Expansion - The effect produced during back washing: the resin particles become separated and rise in the column.

Bed Life - The time that a resin bed is allowed to remain in the adsorption step. With flow rate constant, the bed life equals the number of bed volumes which can be treated divided by the number of bed volumes treated per unit time.

Bed Volume (BV)- The volume of ion exchange resin material in a bed. The volume of the resin in the bed is referred to as one bed volume and is expressed in cubic feet, gallons or liters. (The volume of the resin includes the summation of the volume of each resin particle plus the void volume between the beads.).

Bed Volumes - (or BED VOLUMES TREATED) - A dimensionless ratio that refers to the amount of water, which can be treated, by a bed of resin. The ratio is volumes of water treated per volume of resin in the bed.

BreakThrough - The rapid increase in concentration in the effluent of a substance which signals that adsorption of the substance is near completion and further operation of the column will not be productive. During plant operation, the adsorption cycle is terminated prior to breakthrough of the ion of interest. (The **breakthrough point** can be defined in several different ways such as the point on the breakthrough curve where the concentration of the ion reaches a given value which is half the value of its feed water value**,** halfway between leakage and influent concentration, the MCL or points of inflection. Breakthrough can be gradual or sharp depending on several factors. Some of these points can be difficult to measure unless sharp breakthrough occurs. For example, if the influent nitrate is 10 percent over the MCL, the curve has a flattened or gradual slope when it is at the MCL and the point would be difficult to measure accurately. A consistent definition should be adopted for any given verification plan.)

Breakthrough Curve - Also referred to as EFFLUENT HISTORY or LEAKAGE CURVE. A curve showing the relationship between the bed volumes of water passing through a bed of ion exchange resin and the ionic composition expressed in milliequivalents of the ion per liter in the effluent from the bed over a range to show sharp or gradual changes in the composition of any ion which denotes its break through the resin bed. The BREAKTHROUGH POINT on this curve for nitrate ion is only well defined for fully regenerated resins as the point at which the concentration is one-half of its influent value. The term EFFLUENT HISTORY is also used in this context and is a more general term which denotes a curve of leakage over a treatment range, leakage curves may not show clearly defined breakthrough points.

Brine Use Factor (BUF) - A quantitative expression of salt used in practice to remove nitrate from water by the ion exchange process. The BUF is directly proportional to the salt costs required to operate the process and is also indicative of the amount of wastewater produced by the process. In theory, if the process of nitrate removal were 100 percent efficient, the BUF would be 1. The BUF changes with process and therefor useful in comparing different process designs. Its measured value depends on several other process parameters such as BV treated, nitrate leakage, salt loading, brine concentration, feed water composition, resin characteristics, direction of flow through the bed, method of regeneration or brine recycling etc.

$$\text{BUF} = \frac{\text{Average number of chemical eqivalents of salt used in regeneration}}{\text{Average number of chemical equivalents of nitrate removed by treatment}}$$

In practice and in actual plant operation, inefficiencies are experienced because of the inherent chemistry of the ion exchange process plus the imperfections in process and equipment design. Inefficiencies are introduced in the process design, the physical equipment, generation of wastewater, and operating procedures of a plant. The measured BUF is therefore a reflection of the entire plant operation rather than simply a ratio of two substances. The BUF of an operating system can be estimated by the following formula when the nitrate concentration is expressed as milligrams of nitrate ion per liter of water. (Not as milligrams of nitrogen per liter):

$$\text{BUF} = \left[\frac{\text{pounds of NaCl used per 1000 gallons of treated water}}{4.423(\text{untreated mg N/L - treated mg N/L})}\right]127.1$$

For example, if a plant treats one million gallons of water containing 18 mg-N/L and reduces the nitrate to 4.5 mg-N/L and uses 2000 pounds of salt in the process, the BUF is

$$\text{BUF} = \left[\frac{2}{4.423(18 - 4.5)}\right]127.1 = 4.26$$

Capacity - The number of chemical equivalents of exchangeable ion contained in one liter of an ion exchange material. The volume is measured when the material is wet and is fully saturated with adsorbed water.

Cation Exchange Resin - A resin to which negatively charged ionic sites are bound and which can adsorb cations from an aqueous solution.

Channeling - Cleavage and furrowing in the packed resin bed due to faulty operational procedures, or any condition in which the solution being treated follows the path of least resistance, runs through the channels, and fails to establish close resin contact.

Chemical Equivalent - The amount of any ion, which contains Avogadro's number of ionic charges. The chemical equivalent is independent of the weight of an ion. Thus, one chemical equivalent of nitrate is chemically equivalent to one chemical equivalent of chloride although their equivalent weights differ. SEE EQUIVALENT WEIGHT.

Chemical Stability - The ability of an ion exchange material to resist changes in its properties when in contact with aggressive chemical solutions, such as oxidizing agents.

Chromatography - The separation of ions, molecular species, or complexes into highly purified fractions by means of ion exchange materials or adsorbents.

Clumping - The formation of resin agglomerations in an ion exchange bed due to fouling, chemical depositions, scaling, or admixture with highly cohesive substances, such as certain clays and silts.

Column Operation - The most common method of employing ion exchange materials, in which the liquid to be treated passes through a fixed bed of ion exchange resin held within a cylindrical vessel or column.

Counter Flow Operation - An ion exchange operation in which the direction of flow of water through a bed and the subsequent regenerant flow are in opposite directions.

Cross-Linking - Binding of the linear polymer chains in the matrix of an ion exchange material with an agent which produces a three-dimensional insoluble product.

Cycle - A complete series of operational steps. For instance, a complete cycle of nitrate ion exchange would involve; the complete adsorption step, followed by completion of all other steps and return to the start of the next adsorption step.

Declassification - A resin mixing operation performed on a resin bed. This is used to evenly distribute the nitrate adsorbed on a bed of resin to prepare the bed for the following adsorption step. The operation is performed by using an uneven backwash technique developed at the McFarland, California EPA demonstration plant.

Degradation - The physical or chemical reduction of ion exchange properties due to type of service, solution concentration used, heat, or aggressive operating conditions. Some effects are capacity loss, particle size reduction, excessive swelling, or any combination of the above.

Down Flow - Conventional direction in which water and brines flow through an ion exchange bed during processing, inlet at the top, outlet at the bottom of the bed or column.

Dumping - Refers to removal of large amounts of nitrate, or any other substance, from an ion exchange column as detected by its appearance in the effluent in concentrations exceeding its concentration in the feed water. Nitrate dumping from a resin can occur if sulfate is present in the feed water and if the adsorption cycle is run beyond nitrate breakthrough. This occurs because sulfate ion is able to displace nitrate from the downstream portions of the resin column where nitrate is absorbed. Nitrate dumping does not occur if nitrate selective resins are used or if the concentrations of sulfate and chloride are high such as in regeneration brines.

Effluent - The solution which emerges from an ion exchange column. Synonymous with PRODUCT or TREATED water. The regenerant emerging from the column after regeneration is referred to as the ELUENT or ELUATE.

Elution - The stripping of ions or complexes from an ion exchange material by passing through the bed solutions containing other ions at specific known concentrations.

Empty Bed Contact Time (EBCT)- The time it would take for water to pass through the volume of the column occupied by the resin bed. It is calculated as though the resin is not present, hence "Empty Bed" Contact Time. For example if the one Bed Volume is 700 gallons and the flow rate is 350 gal/min, the EBCT is 2 minutes. Or 0.5 BV per minute.

Entering Ion - The ion involved in an ion exchange reaction which is adsorbed by the resin and which displaces a different ion.

Equivalent - See Equivalent Weight.

Equivalent Weight - The sum of the atomic weights in a chemical formula (the formula weight) for an ion divided by the absolute value of the charge on the ion. This concept is used to compare relative weights of ions, which can interchange or combine with each other as expressed in a balanced chemical equation. For example, the equivalent weight of nitrate ion is 62. The equivalent weight of chloride ion is 35.5 and the weight of sulfate ion is 48. If the weights are expressed in grams, 35.5 grams of chloride ion is chemically equivalent to 62 grams of nitrate ion (or 48 grams of sulfate ion) in an ion exchange reaction. The equivalent weight of sodium ion is 23; thus, 23 grams of sodium is combined with 35.5 grams of chloride ion in 58.5 grams of NaCl. MILLIEQUIVALENT WEIGHT is EQUIVALENT WEIGHT expressed in milligrams of ion per liter. One equivalent weight of nitrate ion is 62 grams. One milliequivalent weight of nitrate ion is 62 mg/L.

Exhaustion - The state of the resin at the end of the adsorption step and when the capacity of the resin for adsorbing the ion of interest is used up. The resin is exhausted.

Fouling - Any deposit or concentration of foreign material on or in an ion exchange material which interferes with the chemical and physical processes. Typical foulants are lubricating oil from pump lubricants, clays, silts, bacteria, algae etc. Fouling can cause reduced efficiency, channeling, loss of resin in back wash and many other plant malfunctions.

Freeboard - The space provided above the resin bed in a vessel or column to accommodate the expansion of the resin bed during the backwash cycle.

Headloss - The loss of liquid pressure head resulting from the passage of water through a bed of ion exchange material.

Hydraulic Loading Rate - The volume of water passing through a given quantity of resin within a given time. Flow rate is usually expressed in terms of gallons per minute per square foot of bed cross sectional area and as gallons per minute per cubic foot of resin. In nitrate treatment these can be 10 to 15 gals/min/sq ft and 3 to 5 gals/min/cu ft.

Influent - The untreated water entering an ion exchange column.

Interstitial Volume - The space between the particles of an ion exchange material in a column or an operating unit (see Void Volume).

Leakage - The presence of a substance, usually nitrate, in the treated water exiting from an ion exchange column before its breakthrough has occurred giving the impression that the substance has "leaked" through the resin bed. Leakage of nitrate from a resin bed is purposely allowed, but controllable, in all process designs because it is virtually impossible to regenerate the resin completely. Leakage is different from Breakthrough.

Leaving Ion - The ion involved in an ion exchange reaction, which is displaced from the resin by a different ion.

Milliequivalent Weight - One one thousandth of the amount in one EQUIVALENT WEIGHT. See EQUIVALENT WEIGHT.

Nitrate Selective Resin same as NITRATE-TO-SULFATE SELECTIVE (NSS) RESIN An ion exchange resin which will adsorb nitrate ions in preference to sulfate from water. The following generalizations obtain: All resins are selective for nitrate over chloride, but may not be NITRATE SELECTIVE. Only special resins (NSS RESINS) are selective for nitrate over sulfate in the range of drinking water concentrations. Also, all resins are selective for nitrate over sulfate at brine concentrations.

Nitrate Concentration - The units of nitrate concentration in the protocol and verification test plan documents must be clearly stated and defined as such in the introductory sections. Nitrate will be expressed as milligrams of the element nitrogen (N) per liter of solution (As opposed to milligrams of NO_3 per liter). The conversion factor is 4.423 times mg-N/L = mg- NO_3/L. California prefers the use of mg- NO_3/L as the expression of nitrate concentration. (Note: The N as the symbol for nitrogen should not be confused with the N representing solution "Normality" which is the expression of concentration in terms of the number of chemical equivalents of a substance per liter of solution.)

Operating Cycle - A single completion of all steps in the process consisting of adsorption, regeneration, rinsing, back wash, stand by.

Osmotic Stability - The ability of an ion exchange material to resist physical degradation due to volume changes imposed by repeated, alternate application of dilute and concentrated solutions.

Partial Regeneration - The regeneration process which is terminated before all of the ions are removed from the bed and replaced by regenerating ions. This is practiced in nitrate removal cases because higher regeneration efficiency can be realized. Regeneration efficiency decreases rapidly with decreasing amounts of applied regenerant. In practical cases for nitrate removal, even complete regenerations will leave some nitrate on the bed because of the strong tendency for nitrate to remain attached to the resin. Processes, which require removal of all nitrate ions (or nearly all), from the bed will require very large amounts of salt and generate large quantities of wastewater.

Physical Stability - The ability of an ion exchange material to resist breakage caused by mechanical manipulation.

Presaturant - The ion adsorbed on the resin by saturating the resin with the ion prior to a column operation. In nitrate treatment the PRESATURANT is chloride ion

Preferred Ion - The one of at least two different ions having equal concentrations that will be adsorbed on the resin to the greatest extent.

Recontamination - The process of removing a contaminant from one point in a water supply and then adding the same and/or other contaminant into the supply at a different point. A problem encountered in ion exchange systems. For example, by incomplete rinsing of resin beds nitrate, chloride, bicarbonate, sulfate and sodium can be added to the supply. Also, by running beds beyond their bed life, nitrate ion can be "dumped" from the bed into the treated water.

Regenerant - The solution used to convert an ion exchange material from its exhausted state to the desired regenerated form for reuse.

Regeneration - The displacement from the ion exchange material of the ions removed during the adsorption (service) run. In nitrate treatment, the regeneration is performed by passing a sodium chloride brine slowly through the bed.

Regeneration Level - The amount of regenerant chemical used per unit volume of ion exchange bed, commonly expressed as lb/ft^3. Also See SALT LOADING.

Resin - Refers to a synthetic ion exchange material. Resins are composed of polymeric water insoluble organic substances, which have been chemically treated to contain chemically charged ionic sites. In nitrate treatment, the resin contains quaternary amino groups, each bearing a positive charge. The quaternary amino groups contain either trimethyl (Type 1), trihydroxyethly (Type 2), or tributyl (NSS, Nitrate Selective) structures.

Rinse - The passage of water through an ion exchange material to remove excess regenerant. Some rinsing action also occurs during BACK WASH and DECLASSIFICATION.

Salt Loading - Salt loading is the amount of regenerant applied to a resin during the regeneration step. It can be expressed in terms of pounds of NaCl per cubic foot of resin, grams of salt/L of resin, equivalents of salt/L of resin or, more conveniently, in terms of bed volumes of brine (volumes brine/ volumes resin) having a specified concentration of NaCl.

The latter method allows expression of salt loading as Bed Volumes (BV) of 1 equivalent NaCl/L of brine. This is equivalent to a salt loading of 3.65 lb. of NaCl/cu. ft. of resin (Derived from 58.5 g/L x 3.781 gal/cu ft/453.6 g/lb). This method allows a direct comparison to the resin capacity expressed in chemical equivalents. For example 1.3 BV of regenerant at 1 equivalent of salt per liter will be chemically equivalent to 1 liter of resin having an exchange capacity of 1.3 equivalents per liter of resin.

The expression of salt loading in terms of BV of brine is a practical consideration. Operation of an ion exchange plant requires some metering of the salt during the regeneration step. This is conveniently accomplished by metering the volume of a saturated brine. The amount of salt can be measured from the volume and brine concentration as determined from specific gravity tables. Salt loading can be expressed in terms of BV of brine in weight percent NaCl. For example, six percent brine contains 3.901 lb/ft^3 and is slightly more concentrated than a brine containing one equivalent of NaCl/L. Salt loading expressed in BV of 6% brine is 1.068 (or 3.901/3.65) times greater than salt loading expressed in equivalents NaCl/L.

<u>Volumetric and Salt Loading Interconversion Factors @ 60°F (Note: 1 BV = 1 L)</u>

Volumetric Conversions:

1 Volume of (6% brine) = 1.068 Volumes of (1 equivalent NaCl/L)

Therefore: 1 BV of (6% brine) = 1.068 BV of (1 equivalent NaCl/L)

1 Volume of (1 equivalent NaCl/L) = 0.936 Volumes of (6% brine)

Therefore: 1 BV of (1 equivalent NaCl/L) = 0.936 BV of (6% brine)

1 Volume of (1 equivalent NaCl/L) = 1 Volume of (5.61% brine)

Therefore: 1 BV of (1 equivalent NaCl/L) = 1 BV of (5.61% brine)

Salt Loading Conversions:

1 BV of (1 equivalent NaCl/L) = 3.65 lb NaCl/cu ft resin

1 BV of (1 equivalent NaCl/L) = 58.5 g NaCl/L resin

1 lb NaCl/cu ft resin = 16.03 g NaCl/L resin

Service Run - The step in the operating cycle during which the water is being treated; i.e., nitrate exchange for chloride. The same as an ADSORPTION RUN.

Set Points - The values of settings, which control the process. These are, Length of Bed Run, Amount of Brine, Amount of Rinse Water, Amount of Backwash and Declassification, Percent Treated in Blend (see "Percent Blend" definition on next page). All are set by controller devices reading totalizing flow meters. If controlled on a time basis, report BOTH time and totalized flow as the setting.

Slow Rinse - That portion of the rinse which follows the regenerant solution and is passed through the ion exchange material at the same flow rate as the regenerant.

SR-6 Resin - A manufacturer's product identification for a strong base ion exchange resin which has three butyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin. The resin is an NSS resin and is highly nitrate selective.

Strong Base Resin - A resin that contains quaternary ammonium ions as the functional group in an ion exchange resin. These groups provide the positive charge sites, which adsorb and hold negatively charged ions such as nitrate, chloride, and sulfate ions.

Throughput Volume or VOLUME TREATED or BV TREATED- The amount of water passed through an exchange bed during the service run before.

Type 1 Resin - A strong base resin which has three methyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin.

Type 2 Resin - A strong base resin which has one hydroxyethyl and two methyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin.

Up Flow - The operation of an ion exchange unit in which solutions are passed in at the bottom and out at the top of the vessel.

Void Volume - See INTERSTITIAL VOLUME.

Voids - The space between the resinous particles in an ion exchange bed.

The following terms were defined in *EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies* (Chapter 1) and will be used in this testing program.

Financing Cost - The cost to finance the purchase of the equipment based on the rates of inflation, borrowed capital, and amortization period. To standardize cost calculations, these factors will be set by the NSF/EPA.

Untreated Water - The raw water that is delivered or available at the site for treatment by the equipment for nitrate removal.

Treated Water - The water stream that has passed through treatment (and post treatment) and is available from the equipment either for direct discharge into a distribution system or for blending with untreated water before injection into the water supply system. The PRODUCT WATER is the water that is injected into the distribution system. It contains TREATED WATER and can also contain UNTREATED water if a portion bypasses the ion exchange vessels.

Blended Water - A mixture of treated and untreated water that is suitable for injection into the distribution system. This is the same as the distributed water. The blending system may or may not be a part of the equipment.

Percent Blend - The percent of treated water that is in the blend. Thus a 75 percent blend will refer to water composed of 75 percent treated and 25 percent untreated water. A 100 percent blended water is equal to treated water.

Maximum Distribution Flow Rate - The maximum flow rate (gallons per minute) of blended (distributed) water which the equipment can cause to be injected into the distribution mains on a continuously operating basis with a nitrate level at or below 80 percent of the MCL.

Maximum Treatment Flow Rate - The maximum flow rate (gallons per minute) of treated water which the equipment can produce on a continuously operating basis while maintaining the Maximum Distribution Flow Rate.

Plant Factor - A factor used in computing water treatment cost. It is the fraction of total time the plant operates or is projected to operate during its period of amortization. NSF will determine this factor to standardize cost computations.

Percent Waste - 100 times the ratio of the annual wastewater production to the annual amount of treated water production.

7.0 TASK 1. PREPARATION, COORDINATION AND START UP

7.1 Introduction

A meeting will be held between the manufacturer and the NSF qualified testing organization regarding the tasks and scheduling of tasks described in the NSF approved PSTP. This task will also include the plant start up if it is not already in operation.

7.2 Objective

The objective of the meeting will be to provide an opportunity for the manufacturer and the field testing personnel to reach a common understanding of the objectives and execution of the testing plan and provide an opportunity to clarify any areas of concern by either party. Initial start up data will be collected if the plant is not already in operation. A tour of the test site can be a helpful part of this meeting. Other personnel associated with the plant should attend if possible, such as the owner/operator and the plant operator and local or state health officials.

7.3 Work Plan

The following items will be covered in this meeting:

- The manufacturer will review the material that was included in the PSTP; in particular, the plant design, operations, outstanding and distinguishing features and especially the treatment objectives and other secondary performance goals claimed for the plant performance. The treatment objectives will be reviewed as stated in the PSTP.

The objectives must include the following:

- The nitrate levels in blended water will be 80 percent of the MCL or less at all times. No nitrate level should occur higher than this level.
- Any secondary standard for any other constituent will not be exceeded at any time.
- Any other objective the manufacturer wishes to include. It is desirable that objectives such as the following be included.
  a) The BUF will average less than 5.0 during the operation period,
  b) The amount of wastewater produced during the operation of the plant will be less than 1.5 percent of the blended water, or

c) The Operations and Maintenance (O & M) cost of producing blended water will be under 10 cents per thousand gallons.

The Field Testing Organization will use diagrams, drawings, plans or on site locations to: Point out the physical limits of the system to be tested, the source water supply, the blending facility and the distribution lines.

- Point out the location of the plant control mechanism, pressure gauges, all control valves, their function, and all instrumentation.
- Point out the alarm system and alarm/shutdown devices and their functioning.
- Point out all safety valve and cross-connection control devices and illustrate how they are tested.
- Walk the testing personnel through the complete operation of the plant, describe the set up and start up procedures and indicate positions of sampling valves and any automatic data collection and recording devices. Indicate where set points are set and what their current values are.

The Field Testing Organization will:

- Review the Schedule for the Testing Plan
- Prepare the Product-Specific Test Plan
- Present the Evaluation Criteria. The plant will be evaluated based on its performance regarding the following:
  - Ability to consistently meet water quality treatment objectives
  - Ability to meet other stated objectives regarding water quality, plant efficiency and wastewater production etc.
  - Sufficiency of cross-connection devices and their reliability
  - Ability to produce product water with acceptable and constant nitrate levels
  - Material balances for water, nitrate, chloride, and sulfate must be established during plant operation test periods
  - Wastewater production
  - Plant Efficiency (BUF)
  - Time and effort required for plant set up and start up
  - Operator time and skills required
  - Maintenance time required
  - Quality of parts and construction
  - Reliability of operation.
  - Functioning of safety devices and alarms
  - Reports of plant inspections

- Quality of the plants data collection and reporting system.
- Costs

- Observe and participate in the plant start up procedures. Record the steps of the start up procedure, note initial set points for the following:
  1) amount of water treated by a single vessel,
  2) amount of brine set for each regeneration,
  3) amount of water used per each rinse,
  4) amount of water used for each backwash, and
  5) percent blend.

The initial set points will be set at the recommendations of the manufacturer.

7.4 Schedule

Before the meeting is held, the Field Testing Organization will provide the Manufacturer with the PSTP containing the Test Plan and any other drawings, plans, site plans operation manuals and similar helpful materials. Sufficient time should be allowed prior to the meeting to allow the testing organization to develop their testing procedure plans and methods to quantify the evaluation criteria. The orientation meeting will be held immediately prior to the first field test period.

8.0 TASK 2. INITIAL PLANT CHARACTERIZATION

8.1 Introduction

Tests will be conducted to get an initial characterization of the plant and to determine if the water quality objectives are being met early in the program. These field tests and data collection activities will be conducted at the start of the testing program to provide a base line for other field tests conducted in Task 3 and at the termination of the test program to see if any operating characteristics change over the test period.

8.2 Objective

The objectives of this task are to establish the initial plant performance characteristics and provide benchmark data which can be referred to for evaluation of long term changes in plant performance when future similar data are obtained. The tests can be repeated at intervals throughout the test program if desired but will be repeated at the end of the test plan.

8.3 Work Plan

At the beginning of the test period, data will be collected from the operating plant, which will characterize the plant performance (e.g., regeneration level, flow, etc.). These tests will be started only after the beds have gone through several cycles at the same settings to allow the plant to reach a steady state of operation. Steady state will be confirmed from nitrate measurements by achieving a material balance of nitrate removed from the treated stream and nitrate removed in the waste brine.

From the following chemical analyses, it shall be determined if the water quality performance objectives are being achieved. If they are not, the manufacturer shall be notified, as they may change the settings on the plant. If changes in settings are significant, the tests should be suspended to allow the beds to reach a steady state. It shall be determined if the objectives are being met from the following analyses:

Samples of Feed Water, Treated Water, and Blended Water will be collected for chemical and biological analyses. The following must be included in the analyses.

- Total Alkalinity
- Bicarbonate
- Chloride
- Nitrate
- TDS
- Electrical conductivity
- Fe
- Mn
- Temperature
- TOC
- HPC
- Algae
- Sulfate
- Sodium
- Calcium
- pH

All analytical data should be reported as mg/L and equivalents per liter of the ion. The nitrate will be reported as both mg-N/L and mg-NO_3^-/L.

The following data shall be measured or observed and recorded from the operating plant.

- Record all set points: Length of Bed Run, Brine, Rinse, Back Wash, Percent Blend, (in units of time, flow rate and total gallons for each)
- Number of vessels in service, regeneration, and standby
  - Flow rate of treated water.
  - Flow rate of blended water.
  - Amount of regenerant (pounds of salt) being used for each regeneration.
  - Inspect the plant equipment including piping for any leaks and scale build up.
  - With help from the operator, at least one vessel should be opened and inspected for piping integrity, dirt, bacterial slime, algae, oil or other foreign material.
  - Estimate the amount of resin in each vessel either by direct inspection or through site glass observations. Use external vessel measurements, corrected for internals and wall thickness. Record the values of one Bed Volume for each vessel.
  - Take a small sample of the resin for resin tests. See section on resin tests below.

While one vessel is in service, the effluent history curves shall be obtained for each major ion (bicarbonate, chloride, nitrate, sulfate) from the start of service to its termination. This is done by collecting grab samples of the treated water at a sample port at or near the exit end of the vessel. (Be sure no other water is mingled with the treated water at the sample point). Flow meter readings and time of collection of each sample or take readings shall be obtained directly from a cumulative flow meter to determine BV of water treated by the vessel at the time of sample collection. At least 20 samples should be collected. The data shall be plotted as mg/L of each ion vs. BV of water treated. The data shall be plotted mg-N/L vs. BV treated.

Any changes in these curves which have occurred since the last measurements shall be noted.

While one vessel is in regeneration, the Field Testing Organization shall:

- Obtain a sample of the undiluted brine and a sample of diluted brine.
- Obtain data for a brine elution curve. This is done by taking grab samples at appropriate intervals of the brine exiting the regenerating vessel. Approximately 20 samples should be taken. Each sample should be analyzed for the four major ions and electrical conductivity. Also from a brine inlet flow meter, determine the amount of brine entering the vessel. Plot the concentration of each ion and the electrical conductivity versus the amount of brine entering the vessel.
- Continue the sample collection after the regeneration from the exit end of the vessel during the rinse period. These samples should be analyzed for the four major ions and the electrical conductivity. During the rinse period, record the amount of rinse water used each time a grab sample is taken. Plot the concentration of each ion and the electrical conductivity versus the amount of rinse water used.
- Estimate the amount of sodium chloride added to the water supply as a result of regeneration and rinsing. This is done as follows: When the above vessel is returned to service, take grab samples of the product water at one minute intervals for ten minutes to twenty minutes. Analyze each sample for the four major ions and the electrical conductivity. Plot the concentration of each ion and the electrical conductivity versus the amount of water treated.
- During the regeneration and rinsing process, record flow meter readings to determine the total amount of waste water produced.
- From the above collected data, make plots (as already mentioned) and calculations as follows:
  - The effluent history curves
  - The brine elution curves
  - The rinsing curves
  - The amount of resin in one BV
  - The amount of salt applied per regeneration in pounds per cubic foot of resin
  - The amount of product water produced per service run
  - The amount of rinse water used
  - The total amount of wastewater (brine, rinse, back wash) produced per vessel per cycle
  - The gallons of saturated brine used per each regeneration
  - The percent blend

  - The percent of wastewater produced
  - The brine use factor, BUF
- From the data collected, determine if the water quality objectives are being met. If they are not, notify the manufacturer. The set points may require readjustment.
- The general appearance and condition of the plant will be noted. Note the general appearance of equipment, new construction etc.

Any changes in this data from the measurements made during the previous test periods shall be noted.

- Resin Tests. Samples of resin will be regularly tested. These tests may be conducted by the testing organization or may be submitted to the resin manufacturer who may do such tests on a routine basis for customers using their products. Tests include, bead integrity or breakage tests done by counting the number whole and partial beads, capacity determinations, and fouling tests made by observation of foreign material and chemical analyses.

8.4 Schedule

The above tests will be conducted at the beginning of the field test period after the plant has reached steady state performance. The tests will be repeated at the end of the field testing period and compared to previously collected data. The field testing organization should coordinate the timing and nature of the tests with the plant owner/operator to be sure the plant is being operated and the proper tools are available for opening the ion exchange vessels for internal inspections.

9.0 TASK 3. DAILY TESTING AND DATA COLLECTION

9.1 Introduction

The plant will be operated and tested on a daily routine basis during the 60-day testing period. Data will be collected to evaluate operator requirements and activity and reliability of equipment.

9.2 Objective

The objective of routine daily testing is to make close observation of plant operation and to provide experience and data to evaluate operational characteristics of the plant such as, ease and reliability of operation, start up and shut down routines, noise production and alarm setting and resetting, reliability of instruments, flow meters, valve operations and similar day to day operator tasks.

9.3 Work Plan

One or more Daily Plant Data Forms will be prepared to include specific data obtained directly from the plant's instrumentation, flow meters and gauges. Each manufacturer will provide a sufficient number of flow meters and instruments for these measurements. Data should be collected daily as described below.

The data which should be collected daily, at the same time each day, includes the following:

- Cumulative flow and gpm of source water and cumulative flow and gpm of treated water
- Cumulative flow and gpm of blended water
- Cumulative flow and gpm of wastewater
- Salt Inventory Estimate

For each ion exchange vessel collect the following data:

- Cumulative flow and gpm of treated water
- Cumulative flow and gpm of brine
- Cumulative flow and gpm of rinse water
- Cumulative flow and gpm of back wash water

Grab samples of raw and finished water streams will be collected once per week for nitrate, chloride, sodium, sulfate, alkalinity, total hardness, calcium hardness, iron, manganese, color, total organic carbon, algae, heterotrophic plate count and electrical conductivity. The samples shall be sent to an analytical laboratory for analysis to reduce cost and increase accuracy. These samples may also be duplicated with on-site field testing kits for immediate results during treatment process adjustments, particularly with the rinse water stream. On-site determination of bed exhaustion and regeneration using conductivity meters is recommended.

Record all instrumentation readings for each stream. Readings will be made each hour from 8 a.m. to 5 p.m. from each vessel.

For each operating ion exchange vessel, the following will be measured and recorded:

- The number of gallons of treated water produced each time the vessel is in Service Mode.
- The number of gallons of brine, and its concentration, used each time the vessel is in regeneration mode as measured at the point of entry into the vessel.
- The number of gallons of rinse water used each time the vessel is in Rinse Mode.
- The number of gallons of back wash water and declassification water used each time the vessel is in Back Wash.

Sufficient data must be collected to enable the calculation of a material balance of total water entering and leaving the vessel and the total solid regenerant entering and leaving the vessel per each cycle.

Summaries of the data collected during the eight hour period will be made and will include the following:

- Total daily water treated by the plant
- Total daily untreated water blended with treated water
- Total daily blended water sent to distribution

- Percent blended water (i.e. Percent of the blended water that is treated.)

Daily summaries for each vessel will include:

- Number of completed cycles
- Total daily water treated
- Total rinse water used
- Total back wash water used
- Total pounds of solid regenerant used
- Total water used to make the regenerant solution

From the above data and chemical analyses, the following will be estimated:

- Material balances for salt and water
- Material balances for nitrate, sulfate, bicarbonate, chloride
- Average untreated water nitrate
- Average treated water nitrate
- Average blended water nitrate
- Amount of salt entering the water supply as a result of incomplete rinsing.
- Brine Use Factor (BUF). Include both completed and incomplete cycles.
- Percent wastewater produced (Percentage of the total water supplied for treatment AND blending that becomes wastewater)
- Cost of regenerant chemical per 1000 gallons of water distributed

9.4 Ion-Exchange Removal Efficiencies

9.4.1 Operational Data Collection

Removal efficiencies of nitrates from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and pressure and finished water flow and pressure shall be collected each hour from 8 a.m. to 5 p.m. per day from each vessel. Table 1 is an example of on-line readings for a daily operational data sheet for an ion-exchange system for 3 shift readings. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific.

TABLE 1: Daily Operations Log Sheet for an Ion-Exchange System

Date:

Parameter	**Shift 1**	**Shift 2**	**Shift 3**
Time			
Initial			
Raw Water			
Q_{raw} (gpm)			
Nitrate (before pretreatment) (mg/L)			
Nitrate (after pretreatment) (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm), (before pretreatment)			
TDS (mg/L)/ Conductivity (μmhos/cm), (after pretreatment)			
P_{raw} (psi)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Ion-exchange Vessel			
Q (gpm)			
Nitrate (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm)			
P (psi)			
Finished			
Q_{fin} (gpm)			
Nitrate (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm)			
Regeneration (@ what % brine or NaCl)			
Q_{regen} (gpm)			
TDS (mg/L)/ Conductivity (μmhos/cm)			

Table 2 presents operational sampling and sample frequency for on-line, field and laboratory analysis. On-line meters and probes should be available for instantaneous recordings. Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 2 at a certified laboratory, except for nitrates, which will be monitored prior to start-up and then weekly. Field sampling should be performed weekly, if samples can not be analyzed in the field then they should be sent to the certified laboratory once a week. Power costs for operation of the ion-exchange equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

9.4.2 Feedwater Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of ion-exchange performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished nitrate concentrations over time for each 60-day test period.
- Plot graph of removal of nitrate over time for each 60-day test period.

TABLE 2: Operating and Water Quality Data Frequency for Ion-Exchange Processes

Parameter	Frequency		
Raw Water Flow	Daily		
Finished Water Flow	Daily		
Regenerant Flow	Daily		
Raw Water Pressure	Daily		
Finished Water Pressure	Daily		
Regenerant Pressure	Daily		
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average		
Hours Operated Per Day	Daily		
Hours Operator Present Per Day	Monthly Average		
Power Costs (kWh/Million Gallons)	Monthly		
Independent check on rates of flow	Weekly		
Independent check on pressure gages	Weekly		
Verification of chemical dosages	Monthly		
Feed Water and Finished Water Characteristics	**On-line**	**Field**	**Lab**
Nitrate	Continuous	Daily	Weekly
Temperature	Continuous	Daily	---
pH	Continuous	Daily	---
TDS/Conductivity	Continuous	Daily	Weekly
Chloride	---	Weekly	Weekly
Sulfate	---	Weekly	Weekly
Sodium	---	Weekly	Weekly
Total Hardness	---	Weekly	Weekly
Calcium Hardness	---	Weekly	Weekly
Total Alkalinity	---	Weekly	Weekly
Iron	---	Weekly	Weekly
Manganese	---	Weekly	Weekly
True Color	---	Weekly	Weekly
Total Organic Carbon	---	---	Weekly
Algae, number and species	---	---	Weekly
Heterotrophic Plate Count	---	---	Weekly

10.0 TASK 4. CROSS-CONNECTION AND MECHANICAL INSPECTION

10.1 Introduction

Professionals will participate in the evaluation and testing program. Testing and inspection of all of the cross-connection prevention devices will be conducted. A professional will also inspect and test all meters, gauges, valves, instrumentation, motors, compressors and similar devices for proper placement and functioning.

10.2 Objective

The objective is to evaluate mechanical, safety and qualitative features of the plant including cross-connection control devices, quality of components, to test cross-connection prevention devices and operation. Assistance of a registered mechanical engineer and a certified cross-connection specialist will be required.

10.3 Work Plan

A Physical Testing and Inspection Schedule and Checklist will be prepared. The checklist will contain the location of all cross-connection prevention devices, air gaps, check valves, block and bleed valves, back flow preventers and similar devices and all electrical and mechanical equipment. The testing will be performed over a time interval to evaluate effects of long term usage.

A site visit by a person certified for inspection and testing of cross-connection prevention devices will be made. A separate report will be prepared by the certified inspector after completing the two following steps.

- All cross-connection prevention devices included in the plant and blending system will be inspected and tested. A piping plan will be supplied and all such devices will be indicated for easy location. The detectors to set off alarms or indicators in event of failure of these devices will also be inspected and tested by simulating failure conditions.
- The piping plan will also be inspected to locate potential trouble spots, where valve leakages, loss of pressure or back siphoning could result in the transfer of waste nitrate and waste salt into the drinking water supply and where safety would be enhanced by providing additional safety devices.

An engineer with specific experience in dealing with ion exchange field equipment will inspect the brine pumps, valves, controllers, compressors, motors, probes, gauges, flow meters, alarms, level controllers, electronic controllers, vessels, storage tanks and similar items on the checklist of mechanical electrical equipment for functional operability, wear, leaks, corrosion, scale build up, and any damages and general suitability. The accuracy and range of gauges and flow meters should be tested or estimated from experience and manufacturer's literature. The performance of valves should be inspected and valve manufacturer data sheets critically reviewed to determine if sufficient closure and sealing is accomplished for the application and for low maintenance operation. The valve type should be noted and if the location and function is appropriate for the type of valve being used. Particular attention should be paid to devices which are subject to corrosion and wear such as brine pumps, other brine system parts and waste brine pumps and storage tanks. All findings will be included in a special reports prepared by the certified mechanical engineer listing those items inspected and an assessment of the condition and an estimate of the lifetime of the item if current usage is extended. The reports should include any specific items, which would require high maintenance, or be particularly costly. The reports will also include an estimate of annual maintenance cost to maintain, service and replace all mechanical and electrical items to allow the plant to operate without interruption.

10.4 Schedule

As stated above, two inspections will be performed; the first inspection will occur at the start of the testing program and the second inspection will be performed after the plant has been in operation for approximately one year. Each inspector will prepare reports after the first inspection and after the second inspection.

11.0 TASK 5. OPERATION EVALUATION AND EXAMINATION OF RECORDS

11.1. Introduction

The direct collection of field data by the Field Testing Organization is considered in this test plan as PRIMARY data. Data collected by others and provided to the testing organization is considered to be SECONDARY data. This task deals with the latter. This other data can be collected by the owner/operator as a part of the regular operating procedures of the plant. This data can be valuable in the evaluation testing program to show consistency of plant performance and to fill in any data gaps which may occur during the brief test periods of primary data collection.

11.2 Objective

The objective is to make an evaluation of the reliability and accuracy of the plant's data collection, management and reporting system used in the regular or routine plant operation and maintenance. If the data collection are found accurate, they can supplement the primary data obtained by the NSF Qualified Testing Organization and will support the evaluations made using primary data. These data can be valuable in the evaluation testing program to show consistency of plant performance and any data missed related to rare incidences of operating and maintenance problems. The secondary data will be obtained with cooperation of the owner/operator from the daily operating logs and records kept by the owner/operator and other reports on plant operation.

11.3 Work Plan

Preparation. At the beginning of the testing program, the testing organization personnel will meet with the plant owner/operator and review the daily or weekly plant operating records and logs used for normal plant operation. The frequency, type, location of recorded data (notebooks, instrument recordings, lab reports etc) should be noted. The records should include the data listed below for easy recall. If appropriate and agreeable, the owner/operator may be requested to provide data on special forms or modem transferable computer files provided by the testing organization.

Secondary Data. The data which should be reviewed will be the following:

- Daily and Weekly data:
  - Total gallons of blended water delivered into the distribution system
  - Total gallons of water treated for nitrate removal
  - Total untreated gallons blended with treated water
  - Percent treated in blended water
  - Total gallons of saturated brine used in the regenerations
  - Total pounds of salt used
  - Total number of regenerations performed
  - Total amount of wastewater produced
  - Percent of water delivered to plant for treatment and blending that becomes wastewater.
- Daily and Weekly records of :
  - Nitrate in treated water
  - Nitrate in untreated water
  - Nitrate in blended water
  - Electrical conductivity of treated water
  - Equipment and parts deliveries
  - Salt deliveries to the plant
- Number of occurrences of the following will be recorded:
  - Nitrate levels in distributed water exceeding 80 percent of the MCL value
  - Electrical conductivity of rinse water exceeding normal levels
  - Alarms and their cause
  - Normal maintenance procedures
  - Unscheduled maintenance activity
  - Unscheduled plant shut downs and their causes

Use of Secondary Data. The above data will be reviewed by the testing organization and a Summary of Secondary Data will be prepared. The following will be estimated on a daily or monthly basis from the Secondary Data:

- Material balances for salt and water

- Average untreated water nitrate
- Average treated water nitrate
- Average blended water nitrate
- Amount of salt entering the water supply as a result of incomplete rinsing
- Brine Use Factor (BUF). Include both completed and incomplete cycles
- Percent wastewater produced. (Percentage of the total water supplied for treatment AND blending that becomes the wasted water.)
- Cost of regenerant chemical per 1000 gallons of water distributed
- Agreement or disagreement with primary data and conclusions based on primary data

An evaluation of the plant's data collection, recording, management and reporting system will be made by comparing the data with that obtained by the NSF Qualified Testing Organization. A general evaluation of the data collection and reporting system should also be made from the standpoint of accuracy, sufficiency, and reliability. Is the system giving enough data to tell if the manufacturer's performance objectives are being met? Is too much data being obtained and is the interpretation confusing? Are alarms recorded? Is there enough and accurate data for the operator to determine if the plant is operating efficiently? Is the data recall system reliable and is the data easy to find and well organized?

11.4 Schedule

The secondary data for this task will be the normal operating data collected by the owner/operator throughout the 60-day test period concurrent with the test program. The secondary data will be made available to the testing organization on a weekly basis. If additional secondary data are required, the testing organization will make a request for it at the initial meeting.

12.0 TASK 6. CONTINUOUS NITRATE ANALYSIS AND MONITORING

12.1 Introduction

Consistency, reliability and stability of the operation of an ion exchange plant to produce water of acceptable quality should be tested on a continuous basis, during a 60 day uninterrupted period in the testing program. Consistency and reliability relate to the long-term operation, while stability relates to absence of spiking and fluctuations which may occur during a relatively short term and which may cause plant disruptions or maladjustments. Nitrate analysis by occasional grab samples say one or two per day, is not frequent enough to detect fluctuations which may occur in the product water or other streams.

Fluctuations or swings in nitrate levels may be expected to some extent because of the cyclic nature of the ion exchange processing. When a resin bed is placed into service, the water quality may change throughout the bed run up to the regeneration. Any given bed may undergo up to about five regenerations per day. For example, after regeneration, some nitrate remains on the bed. If the bed is improperly rinsed or declassified, high nitrate spikes can occur at the start of the run. Also, if nitrate increases during the run, or the end of run set point malfunctions or is set too long, an over run may occur which is the cause of "dumping" high nitrate into the product water. Malfunction of equipment during regeneration or rinsing can also cause high nitrate levels to rapidly rise in the product when the vessel is returned to service. Malfunctioning, slow operating, or stuck valves may also cause similar problems.

If the fluctuations become extreme the plant is described as "unstable" and can be the cause of two major problems.

1) The water quality standard and treatment objective may be violated, and
2) The plant may be thrown into an upset, which could cause serious water supply and water quality violations.

These upsets would be caused by set point changes which either the instrumentation or the operator is basing on grab sample analyses, which are not typical or average. For example, if a high nitrate analytical result is obtained, an automatic instrument may cause a vessel to go off line and regenerate prematurely. This in turn can cause a water supply failure and an excessive use of salt.

The above plant malfunctions can best be detected by doing continuous, on stream analysis. Strictly speaking, the best and most reliable analyzers can only do grab samples in rapid succession. Ion chromatography instruments or instruments using ultraviolet detectors can make analyses at a frequency of about 12 analyses per hour. One or more of these instruments should be employed in this testing procedure.

12.2 Objective

The objective is to test the consistency, reliability and stability of the plant to produce water meeting the water quality nitrate objectives. This will be done by monitoring the nitrate levels in three different streams and one monitoring stream by using automatic, continuous, on site, 24 hour per day sampling and analysis for a period of 60 days.

12.3 Work Plan

Preplanning: The most active season of nitrate plant operation should be determined prior to the start of the testing program. Some plants operate only during summer periods of high water demand others are most active during the growing season when fertilizers are used. A site plan will be prepared to show, housing, location of equipment, benches, sinks, sample taps, sample lines, electrical power and drainage. Location of computer and/or recording instruments will be shown. If modems are used, show locations of telephone access lines. More than one analyzer may be needed.

Set Up: Allow one month for set up and testing the analyzer. The nitrate analyzer will be set up in an enclosed area at the plant site and separate sample lines will be connected to supplies of treated, untreated, blended, and a monitor supply, for delivery to the analyzer. The monitor supply will be provided from a batch container and will be prepared from chemical standards having a nitrate composition of 10 mg N/L and the approximate composition of bicarbonate, chloride and sulfate in the product water. Flow of sample will be regulated or delivered via timed sample pumps to prevent sample contamination from other water sources. A calibration standard will be used as recommended by the manufacturer of the analyzer.

Operation of Analyzers: Continuous nitrate analyses will be performed for a period of 60 days on each of the three streams of blended water, treated water and untreated water. The analyzers will be programmed to sample each stream in succession. A sample from the monitor solution will also be analyzed to allow corrections to the nitrate data to be made.

Automatic analyzers usually have provisions for chart recording or serial ports for transfer to computer files. The latter can be stored in the computer and also delivered to remote locations vial modem transfers. The latter would have the advantage of low cost data management and collection by the testing organization.

Data Interpretation: The data collected on the three different streams can be rapidly and easily examined in the form of computer data files and spreadsheet graphics. The following data should be obtained:

- Total number of nitrate analyses obtained from each stream
- Average nitrate level obtained over each 24 hour period, each week, and for 60 days
- Standard deviation for each stream
- Number and frequency of exceeding water quality objectives
- Number and frequency of nitrate spikes
- Duration of nitrate spikes
- Relation of spikes to daily time
- Relation to diurnal temperature as obtained from local weather data
- Relation to vessel cycles as recorded by plant operator
- Relation to operator activities as reported by operator
- Relation to maintenance operation as reported by operator
- Relation to water production as reported by operator

12.4 Schedule

Task 6 will be conducted over a continuous 60 day period which can coincide with other scheduled tasks.

13.0 TASK 7: QUALITY ASSURANCE AND QUALITY CONTROL

13.1 Introduction

Quality assurance and quality control of the measured water quality parameters shall be maintained during the Verification Testing program.

13.2 Objective

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program to provide accurate data from which reliable conclusions and evaluations can be made. Maintenance of strict QA/QC procedures and records is important, in that if a question arises when analyzing or interpreting data collected for a given test or experiment, it will be possible to verify exact conditions at the time of testing through procedure and record recall.

13.3 Work Plan

13.3.1 Plant Metering Devices

Metering devices, flow meters, pressure gauges, thermometers, sensors, analyzers, probes, and associated electronic signals should be inspected and verified to be working or not on a routine basis. A daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with other meters registering the same flow stream and that the signal being recorded is correct. Accurately calibrated flow meters may be attached to the plumbing to aid calibration.

Accuracy of readings need be verified at least once per week.

13.3.2 On-Site Analytical Methods

Use of portable field test equipment will be used unless regular laboratory wet chemical capabilities are available for the on-site measurements. Accuracy of calibrated field kits should be determined by comparison with split sample analysis by a certified lab. For all sample collections, preservation and storage for later analysis and the analyses themselves should be done according to recognized procedures listed as acceptable for drinking water in Standard Methods or EPA Methods.

13.3.3 Nitrate Grab Samples

Nitrate analyses will be the most frequently performed analysis. It is very convenient to use the field test kits commercially available for drinking water samples such as Hach NI-11 and similar kits. A variety of kit types are available ranging in price and sophistication. The procedures for using the kits should be carefully followed. In addition, it has been found that results can vary with the individual preferences and practices. Colorimetric comparators are particularly troublesome. The nitrate measurements should be made by one person who has practice and proven competence with the method.

If a color comparator using a color graduated circular disk is used the following precautions should be made.

1) Read against light reflected from a white panel lit by a good white light dispersed light source such as a fluorescent bulb.

2) Never use sky light or sunlight.
3) Use the same light source and position for all readings.
4) Calibrate against known standards.
5) Make a new calibration if the analyst changes, the light source changes, the color wheel changes, at least once per week in any case.

In any case, regardless of the kit used, a calibration should be performed against known standards once per week and every tenth sample should be a sample of known concentrations.

13.3.4 Continuous Nitrate Sampling and Analysis

The use of continuous sampling nitrate analyzers was discussed under a separate section of this test plan. These instruments can be programmed for calibration at set intervals. The use of a monitor solution is also recommended to save calibration solution and time. The monitor solution should be a batch source of known concentration containing representative concentrations of the other major ions. Corrected readings will be based on both the monitor readings and the standard solution readings.

13.3.5 Chloride, Sulfate, Alkalinity

Laboratory and field test kits are also available for doing analyses for these ions. The kit selected should use methods listed in Standard Methods. Each method should be field calibrated over a range of concentrations available in the various streams subject to analysis. Split samples should also be submitted to a state certified laboratory for checking accuracy of the field kit analysis.

13.3.6 Off-Site Analyses

Inorganic chemical samples shall be collected and preserved in accordance with Standard Method 3010B. The samples should be refrigerated at approximately 2 to 8°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8$^{\circ\circ}$C. Samples shall be processed for analysis by a state-certified, third party accredited or EPA accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8^{o}C until initiation of analysis.

14.0 TASK 8. DATA COLLECTION METHODS, MANAGEMENT AND REPORTING

14.1 Introduction

It is important to give considerable thought prior to the start of any data collection regarding the collection methods and management of data. Data management and the reporting and evaluation of the data should be integrated with each other because of the limited time allowed for the testing plan.

The data collection methods used in the verification testing program shall involve the use of manual field note books, logs, field forms and/or computer files of software programs. Any software used must be compatible with NSF software preferences. It is particularly important that data from the continuous nitrate analysis instrumentation be kept on computer files, as this provides a convenient method of collection, transfer, storage and evaluation.

It should be considered from the outset, that the method of data collection and management employed by the plant owner/operator was designed in response to plant operation and regulatory reporting and should not be a primary source of the data required by the testing plan. Plant testing is not an objective of plant operation. The primary objective is to provide safe drinking water to the public. Consequently, it is preferred that the field testing organization remain as independent as possible from the data system adopted by the owner/operator. The data collection and management system used for daily plant operation is itself a part of the plant and is evaluated in Task 5 above. Valid testing should therefore be done using independent methods of data collection and management.

14.2 Objective

The objective of this task is to implement methods of data collection, management, and evaluation which are consistent with the testing plan and prepare the final report product.

14.3 Work Plan

14.3.1 Manual Methods

The field testing organization will prepare data forms or log forms to be used by their personnel to collect the data required for each of the specific tasks as described above. One individual, the Data Manager, will be assigned the data management task. All original completed data forms and logs will be submitted to the Data Manager for filing and transfer. The Data Manager will be an engineer or scientist experienced in water treatment and testing and will be closely involved in the testing plan on a daily basis. The Data Manager will compile the manually obtained data into computer files for use in spreadsheets or other data management software and retained for data evaluation. The Data Manager will also review data and make evaluations regarding water quality objectives and plant characteristics based on current data. The Data Manager will also organize the data according to the outlines of the quarterly and final reports and be active in the preparation of the reports.

14.3.2 Automatic Methods

Data from automatic recording devices may be transferred to electronic files for storage and recall either with field computers or by remote transfer to the Data Manager for the project. If available, the Data Manager shall download the files once a day during automatic data collection periods. The data from the automatic nitrate analyses is an example of this application.

14.3.3 Secondary Data

The data collected by the plant owner/operator is considered as secondary data in this testing plan. The Data Manager will coordinate the collection of secondary data with the owner/operator.

14.3.4 Data Interpretation

The data will be interpreted in light of the water quality objectives and other operational objectives to verify the plant performance.

14.3.5 Report Preparation

The report will be organized by task number plus other sections appropriate for the 60-day test period and will contain a description of all data obtained during the test program. The report will include an executive summary, data summaries, data charts, data tables, and conclusions, which can be drawn concerning the plant performance and the achievement of performance objectives.

The final report will contain an Executive Summary that will include the following information given in brief tabular form:

- Plant Identification:
  - Design classification of the equipment
  - Location of the test site
  - Maximum flow rate, g.p.m.
  - Duration and dates of testing period
- Achievement of Objectives:
  - Whether or not the water quality and secondary objectives were achieved
  - Cases, if any, where the plant failed to meet objectives
- Performance Characteristics:
  - The amount of salt used per day, per month, per year
  - The amount of salt used to produce blended water, pounds per 1000 and million gallons
  - The average BUF of the operating plant
  - The cost of regenerant per 1000 gallons of blended water
  - Percent of wastewater produced
  - Instances of operational problems or difficulties
  - Evaluation of equipment quality, construction and service

  - Evaluation results of cross-connection devices
  - Number of shut down alarms during operation
  - Maintenance level required
  - Overall rating and evaluation
- Estimated Cost:
  - Annual maintenance cost
  - Annual operating cost including capital amortization
- Projections:
  - The performance characteristics of the plant and costs will be projected for various representative compositions of feed water with (1) greater and (2)lesser amounts of each of the four major anions.

14.3.6 Report Submission and Comments

A draft final report will be submitted to the manufacturer for comments. The final report will address the comments of the manufacturer.

14.4 Schedule

The data collection methods and data management will be in effect throughout the test program. A draft final report will be submitted after the 60-day test period followed by a final report.

15.0 OPERATIONS AND MAINTENANCE

The following are recommendations for criteria for O&M Manuals for ion exchange equipment and should be evaluated by the Field Testing Organization during verification testing.

15.1 Maintenance

15.1.1 Component Maintenance

The maintenance section will include references to equipment manuals, which describe maintenance procedures and calibration procedures. Refer to manuals prepared by each manufacturer of each component, which requires maintenance. The manufacturer's manuals must be provided in an appendix. Summarize the maintenance and calibration procedures, which are recommended by the manufacturer of each of the major components, valves, meters, instruments and controllers.

Provide a Maintenance and Calibration Schedule or Table indicating recommended frequency of maintenance and the specific maintenance activity for each maintained component.

15.1.2 Plant Maintenance

The following items must be addressed regarding general plant maintenance:

- Testing resin samples for capacity and breakage.
- Inspection and cleaning of vessel interiors and ion exchange resin.
- Inspection of all piping connections for leakage.
- Keeping the plant area clean and free of debris.
- Inspection and renewal of painted surfaces such as vessels, piping, housings, etc.
- Inspection of sample lines for free flow samples.
- Inspection of all valves for leakages.
- Inspection and maintenance of all back flow preventors and cross connection devices for leakages and/or malfunctioning.
- Inspection and maintenance of air pressure throughout the system for automatic valves.
- Inspection of all electrical cables, voltages, and heat production areas and devices.
- Inspection of brine pumps and brine leakages in brine maker area.
- Inspection of fire extinguishers, air packs, showers, eye washes and other safety devices.
- Inspection of controller cables, cabinet interiors, relays, heat generation and functioning.
- Inspection and routine tests of computer components, printers, modems, etc.
- Supply of salt for brine making.
- Chemical supplies for analytical devices and procedures.
- Supply of analytical sampling bottles.
- Supply of recording paper and computer printer paper.
- Any other items required for proper plant operation.

15.2 Operation

The operation manual section should be prepared by a person who has field experience and has actually operated the equipment and can give a clear description of theory and practice of operation. Input from design engineers or other office-confined personnel should be minimized. The material must be presented from the plant operator's point-of-view and should not be highly technical or engineering oriented. The operation of each major component must be addressed without reference to equipment brochures supplied by subcomponent suppliers.

- **Water Quality Objectives**: These shall be of primary importance.
- **Theory of Operation**: Text and diagrams shall be provided, as well as a section on

terminology. These materials shall be at a level understandable by plant operators.

- **Description of the Process**: Text and diagrams shall be provided, as well as a section on terminology.
- **Flow Diagram**: Normal operating flow rates and daily cumulative amounts shall be shown.
- **Piping and Instrumentation Diagram**: A non-engineering presentation that can be understood by non-engineer plant operator shall be provided, referencing all valves and components according to ID labels placed on all components (valves, piping, flow direction, etc.). An ID label and a clearly marked indicator of OPEN or CLOSED status shall be provided for each valve.
- **Automatic Controller(s)**: The principle of operation shall be described and the start up and shut down procedures, reagents required, calibration procedure, accuracy and interface and plant shall be given.
- **Manual Operation**: Method of operation if controllers fail to function shall be described.
- **Data Collection and Recording Devices**: A section for each device shall be provided, describing the operation and accuracy and calibration procedure.
- **Location and Operation of Meters and Instruments**: Each item shall be specified and an ID label given.
- **Alarms**.

A section on each of the following shall be included:

- Start-up procedure
- Plant settings, service batch, blend percent, brine batch, rinse and backwater water
- Plant monitoring procedure
- Expected typical performance
- Manual shutdown of the plant
- Restarting the plant after manual shut down alarms
- Restarting the plant after automatic shut down alarms
- Alarm removal procedure
- Reinitializing and restarting
- Adjusting the plant settings to lower nitrate levels
- Adjusting the plant to increased nitrate levels
- Adjusting plant to reduce salt consumption
- Adjusting plant to reduce waste production
- Adjusting plant in response to changes in untreated water composition

16.0 REFERENCES

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Distribution Valves: Selection, Installation, and Field Testing. AWWA Manual M44.

Regulations Relating to Cross-Connections, California Administrative Code, Title 17, Public Health, 1956.

Table 3. Analytical Methods

Parameters	Laboratory *Standard Methods*[1] number or Other Method Reference	Laboratory EPA Method[2]
General Water Quality		
pH	4500-H^+ B	150.1 / 150.2
Total alkalinity	2320 B	
Temperature	2550 B	
Conductivity	2510B	120.1
Total Dissolved Solids	2540 C	
Color	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Inorganic Water Quality		
Nitrate	4110 B / 4500-NO_3^- D, F	300.0 / 353.2
Chloride	4110 B / 4500-Cl^- D	300.0
Sulfate	4110 B / 4500-$SO_4^=$ C, D, F	300.0 / 375.2
Sodium	3111 B	200.7
Calcium Hardness	3500-Ca^{+2} D	
Total Hardness	2340 C	
Alkalinity	2320 B	
Iron	3111 D / 3113 B / 3120 B	200.7/200.8/ 200.9
Manganese	3111 D / 3113 B / 3120 B	200.7/200.8/200.9
Bicarbonate, HCO_3	Calculation	
Organic Water Quality		
Total organic carbon	5310 C	
Microbiological		
Algae, number and species	10200 F	
Heterotrophic Plate Count	9215 B	

Notes:

1) Standard Methods Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).